

Chapter 4. Sediment Transport and Geomorphic Conditions

Study Area Geomorphology

This section of the report is organized by subreaches, which are defined in Table 1.1 and shown on the map in Appendix A. In addition, a number of the field photographs (plates), located in Appendix B, are referred to in this section of the report to describe conditions within the subreach.

Subreach 5

Base level control for the study area of the San Joaquin River is the Merced River alluvial fan that has prograded out onto the valley floor of the San Joaquin River (Plate 1). The combined effects of tectonically driven subsidence (Janda 1965, Ouchi 1983) and fan progradation into the valley have effectively reduced the slope of the San Joaquin River upstream of the Merced River confluence, and a multi-channeled, anabranching or anastomosed river planform has developed (Nanson and Knighton 1993) (Plate 2). Anastomosed river systems tend to be indicative of low hydraulic energy and lateral stability because of erosion-resistant banks and aggradation (Knighton and Nanson 1996). Anabranching rivers, however, tend to have more hydraulic energy, extended flood hydrographs, and an ability to maintain water and sediment transport where there is very limited ability to increase the channel slope (Nanson and Huang in press). The multi-channeled anabranching planform concentrates hydraulic energy where flows would otherwise be dispersed into the overbank areas. Restrictions on slope adjustment can result from valley obstruction, subsidence, and tectonism. As can be seen on Plate 3, where there is evidence of dynamic lateral migration of the channels in the form of meander scroll topography, the San Joaquin River and the sloughs appear to meet the requirements for an anabranching system, as opposed to a laterally stable anastomosed system. The topography of the river, the sloughs, and the floodbasins in this subreach are shown on 1914 cross sections 81 and 78 in Appendix C. Cross section 85 (Appendix C) shows the topography where the anabranching system is forced back into a single channel through the valley contraction at the Merced River fan.

Subreach 4B

The downstream limit of this subreach is defined by the confluence of the mainstem San Joaquin River and the flows that reenter the river from the Eastside Bypass (Plate 4). Historically this subreach of the river was an anabranching system, with the flows being divided into the meandering San Joaquin River (Plate 5) and the sloughs, including Mud, Salt, and Sand Sloughs. Downstream of the Mariposa Bypass at RM 147, the present channel of the San Joaquin River periodically conveys flood flows. However, between the Mariposa Bypass and the head of the subreach at the Sand Slough Control Structure, flows are kept to as low as 300–400 cfs, and the river channel has a reduced capacity for higher flows (Plate 6). The historical topography of the subreach is represented by 1914 cross sections 70 and 58 in Appendix C.

Subreach 4A

The Sand Slough Control Structure at the downstream limit of this subreach presently controls the distribution of flows between the San Joaquin River and the Eastside Bypass (Plate 7). Historically, this subreach of the river was anabranching, as can be seen on cross sections 53 and 48 in Appendix C. The San Joaquin River within the subreach had low sinuosity (the ratio of channel length to valley length) (about 1.3), and the amplitude of the bends was also low. For most of the year, this subreach of the river is dry (Plate 8) and vegetation-supporting flows are derived from leakage at the Sack Dam (Plate 9) or possibly seepage from the canals that border the river (Plate 8). Flows that were historically conveyed in the sloughs are now conveyed in the Eastside Bypass system.

Subreach 3

The downstream limit of the subreach is essentially defined by the head of the flood basin in which the anabranching channels of the San Joaquin River and the sloughs functioned historically to store and convey flood flows. Upstream of the flood basin, the San Joaquin River was a single-thread, moderately sinuous (1.4), meandering river with bends of moderate amplitude that was confined between a terrace on the west and the margins of the eastside alluvial fans (Plate 10). Urban development at Firebaugh (Plate 11), local levees, and the agricultural water-distribution canals that flank the river (Plate 12) have limited the historical floodplain of the river. Flooding of the Town of Firebaugh occurs when discharges approach 5,000 cfs. Downstream conveyance of Delta-Mendota Canal water through the subreach has promoted the development of riparian vegetation along the channel. Cross sections 36 and 29 in Appendix C show the single-thread channel, but they also show the presence in 1914 of the Columbia and Poso canals and the confining effects of the canals on floodflows.

Subreach 2

The head of subreach 2 is the intersection point for the modern-day alluvial fan of the San Joaquin River. Outside of the levees, there are remnants of the distributary channels of the modern fan. Historically, the Mendota Pool was the location of the confluence of the San Joaquin River and the Kings River North (Fresno Slough), where flood flows from the Tulare Basin were conveyed into the San Joaquin River (Plate 13). Currently, the pool is a sediment trap that creates backwater conditions upstream into this subreach of the San Joaquin River and into Fresno Slough during flood flows (U.S. Army Corps of Engineers 1993). The historical sinuosity of the subreach was high (2.33), and many of the bends were of high amplitude (Plate 14). The high sinuosity of the subreach can be explained by the steeper valley slope as the river descends down the dip slope on the flank of the subsiding basin, before it flows north along the lower gradient axis of the basin (Ouchi 1983). The head of the Chowchilla Bypass and the first flood flow bifurcation in the flood control system is located at RM 216 (Plate 15). Backwater from the dual control structures results in significant sediment deposition in the San Joaquin River, and sediment transport proportionate to the flow split also causes significant sediment deposition in the bypass, where an approximately 200,000-cubic-yard sediment trap is located. Highly erodible banks are the source of most of the sediment that is stored within the channel in this subreach, which reduces in-levee flood control capacity (Plate 16). The upstream end of the subreach is at Gravelly Ford, which marks the downstream terminus of the terraces that flank the river and confine flood flows (Plate 17). The historical topography of the subreach and the transition into the terrace-confined section of the river is shown on cross sections 19 and 14 in Appendix C.

Subreach 1B

From Gravelly Ford upstream, the San Joaquin River is a low-sinuosity (1.2), meandering stream inset below Pleistocene and more recent-age terraces. The channel is bound by up to three terraces (Plate 18). The highest terrace is at least 40 feet above the present bed of the river, and the intermediate terrace is about 20 feet above the bed of the river. Where sand and gravel mining have caused significant degradation of the bed, the former floodplain surface has become a terrace about 10 feet above the bed of the channel (Plate 19). Flood flow regulation and low-flow releases from Friant Dam have encouraged the development of a riparian vegetation fringe along the channel. The historical topography of the subreach and the flanking terraces can be seen on cross sections 9 and 2 in Appendix C.

Subreach 1A

From Herndon upstream to Friant Dam, the San Joaquin River is inset below the flanking terraces. Prior to extensive in-channel and channel-margin sand and gravel mining, the river had a low-sinuosity meandering planform (Cain 1997). However, the aggregate extraction has in many areas caused the formation of a multi-channeled river where berms between the river and gravel pits were breached or overtopped (Plate 20). Significant degradation has been attributed to the aggregate mining (Cain 1997), and reachwide degradation would probably have been greater if local outcrops of bed material were not providing local base level controls in the subreach (Plate 21). Except for low-flow releases required to maintain existing water rights and flood flow releases, the water yield from the San Joaquin River basin upstream of Friant Dam are dispersed through the Madera and Friant canals (Plate 22). The 1914 survey did not extend upstream of Herndon, and, therefore, cross sections of that era are not available to show channel and overbank topography in a relatively unmodified condition. However, an extensive survey of the subreach was conducted by the USBR in 1938. Figures 4.1. and 4.2 show the 1938 cross section and a repeat survey cross section in 1996 (Cain 1997) at RM 258.8 and RM 265.3, respectively. At both locations, the repeat cross sections show that the channel degraded between 1937 and 1996.

1914 Channel Characteristics

The 1914 survey of the study area provides a baseline condition for the river subreaches (5, 4B, 4A, 3, 2, 1B) between the Merced River confluence at RM 118 and Herndon at RM 243. Eighty-five cross sections were surveyed within the study area and used to construct longitudinal profiles of the river thalweg (minimum elevation at the cross section), water-surface elevation at the time of the surveys, and the top of bank elevation (Figure 4.3). The top-of-bank profile represents the elevation of the bank at each cross section that defines the bankfull stage of the channel. The width of the channel at the bankfull stage was measured from the cross sections and plotted against the river mile to show the spatial distribution of the widths (Figure 4.4). Channel depth at bankfull stage was also determined at each cross section and plotted against river mile to create a longitudinal profile of the study area (Figure 4.5). The width-depth ratio at the bankfull stage was computed for each cross section and plotted against river mile (Figure 4.6). Average values for the valley slope (top of bank), channel slope, bankfull width, bankfull depth, width-depth ratio, and sinuosity were computed for each of the subreaches (Table 4.1).

Valley Slope and Sinuosity

The data in Table 4.2 show that the valley slope gradually flattens from about 0.00077 (4.1 ft/mile) in subreach 1B to 0.00036 (1.9 ft/mile), with subreach 3 (Mendota to Sack Dam) being the flattest at 0.00033 (1.7 ft/mile), where the channel occupies the axis of the subsiding basin (Ouchi 1983). The channel slope shows the same decreasing trend downstream, with the steepest slope being in subreach 1B (0.00063) and the flattest being in subreach 5 (0.00021) immediately upstream of the downstream base level control at the Merced River alluvial fan. Channel sinuosity, which can be defined either as the ratio of the channel length to the valley length or the ratio of the valley slope to the channel slope, varies from a low of 1.2 in subreach 1B to a high of 1.8 in subreach 2, where the channel flows down the dip slope of the basin (Ouchi 1983). Sinuosity is low in subreaches 3 and 4A, where it is 1.4 and 1.3, respectively. Subreaches 4B and 5 have very similar values (1.7). The lowest sinuosity within the axis of the valley is found in subreach 4A (1.3), where the channel planform changes from single thread meandering to anabranching (Nanson and Huang in press).

Channel Width and Depth

The channel-width data in Table 4.1 indicate that the channel becomes progressively narrower in the downstream direction from subreach 1B (875 feet) to subreach 4A (277 feet), where the multi-channeled anabranching system commences. Channel widths increase again in subreaches 4B (311 feet) and 5 (386 feet). Average channel depths at bankfull stage are remarkably constant from subreach 2 to subreach 4A (14 feet). Depth is highest in subreach 1B (18 feet) and lowest in subreach 4B (9 feet). Channel depth increases to 13 feet in subreach 5. Width-depth ratios show a general decrease in the downstream direction from about 50 in subreach 1B to 20 in subreach 4A. Width-depth ratios increase again in subreaches 4B and 5 to 35 and 30, respectively. The width-depth ratio trends can be correlated with the resistance to erosion of the channel banks (Schumm 1963). The subreaches with a higher width-depth ratio have more erodible banks (Plate 24), whereas those with lower values have more erosion-resistant banks (Plate 26). The lower values of width-depth ratio in subreaches 4A, 4B, and 5 are also consistent with the required channel adjustments to maintain the continuity of sediment and water through the lower subreaches, where there is a rising base level (Nanson and Huang in press).

Morphometric measurements of the sloughs were also made from the CDC cross sections in subreaches 4A, 4B, and 5 (Table 4.2). In subreach 5, the slough and channel slopes were the same (0.0002). However, in subreach 4B and 4A, the slough slopes were about 50% steeper than the mainstem channel slope, which again is consistent with channel adjustment in an anabranching subreach (Nanson and Huang in press). The average width of Salt Slough in subreach 5 (394 feet) is actually higher than that of the mainstem river (386 feet), but the average depth in the slough (10 feet) is less than that of the mainstem channel (13 feet). With a higher width-depth ratio (39), Salt Slough has

a slightly lower sediment transport capacity than the mainstem river (30) in subreach 5 because the sediment transport capacity is inversely proportional to the square of the width-depth ratio (Rubey 1952). Table 4.2 shows that the average widths and depths of the sloughs in subreaches 4A and 4B are less than those of the mainstem river. Width-depth ratios are similar for the sloughs and the mainstem, but because the sloughs are steeper, the sediment transport capacities of the sloughs are higher in these subreaches (Colby 1964).

Baseline data for subreach 1A and 1B do not exist, because the 1914 CDC survey ceased at Herndon (RM 243). Cain (1997) used the USBR 1939 survey of the subreach as a baseline for his analysis of changes in the subreach. Water-surface slopes in the subreach ranged from 0.0005 (2.6 ft/mile) to 0.0008 (4.2 ft/mile) at the upstream end. Assuming that the active channel was equivalent to the bankfull or dominant discharge channel (Leopold et al. 1964), Cain (1997) showed that the average active channel width in the subreach was about 1,200 feet in 1939. The average low-flow channel width in the subreach in 1939 was about 300 feet (Cain 1997).

Channel Width and Depth Changes Between 1914 and 1998.

Twelve cross sections that were originally surveyed in 1914 were resurveyed in 1998 (Chapter 2). Morphometric data were extracted from the 1998 cross sections so that these could be compared with the values established from the 1914 survey (Table 4.3).

Subreach 5

At the downstream end of the subreach, cross section 85 shows almost no change in channel dimensions, which suggests that the degradation recorded by the USGS between the Merced River and Vernalis (Simpson and Blodgett 1979) did not extend into the study area. At cross section 78 in subreach 5, the channel of the San Joaquin River appears to have both widened and deepened, but the width-depth ratio remained essentially the same (21 versus 19). The changes in the size of the channel could be the result of the hydrological changes imposed by the bypass system. Historically, the flows were distributed at this latitude among the sloughs and the mainstem. The Eastside Bypass conveys a significant portion of the flood flows to a point at the head of the subreach where they are discharged to the mainstem. The concentration of flows in this area may well be responsible for the increased channel size (Schumm 1977).

Subreach 4B

Cross section 70 in subreach 4B appears to have widened but become more shallow (Table 4.3). This cross section is located downstream of the Mariposa Bypass, and the flow concentration may have caused channel widening. Local bank erosion and conveyance of sediment from the Eastside Bypass to the mainstem via the Mariposa Bypass could be responsible for the aggradation. The channel at cross section 58 has narrowed from 230 to about 140 feet, which is totally consistent with the regulation of flows at the Sand Slough Control Structure at the head of the subreach.

Subreach 4A

In subreach 4A, cross sections 53 and 48 show opposing trends (Table 4.3.). Both channel width and depth increased at cross section 53, but both width and depth decreased at cross section 48.

Subreach 3

In subreach 3, the channel consistently narrowed at cross sections 36 and 29, but the depth at cross section 36 decreased whereas it increased slightly at cross section 29. The substantial change in channel width at cross section 29 could be due to a slight change in the alignment of the repeat cross section survey. However, channel narrowing is the expected response of the reduction in flows resulting from the flood bypasses and reduction of flood flows from the Kings River North (Schumm 1977).

Subreach 2

In subreach 2, cross sections 19 and 14 also show opposing trends (Table 4.3). Cross section 19, located downstream of the Chowchilla Bypass Structure at RM 216, shows channel widening, but little change in channel depth. In contrast, the channel narrowed and deepened at cross section 14. The changes at cross section 14 could be a result of local extraction of sand and gravel from the channel between 1986 and 1995 (Hill pers. comm.).

Subreach 1B

In subreach 1B, cross sections 9 and 2 also show opposing trends (Table 4.3), which is not unexpected, considering the extent of sand and gravel mining that has

occurred in the subreach (Cain 1997). Cross section 9 is located in a subreach that was severely mined, and the channel appears to have widened. At cross section 2, the channel appears to have become narrower and shallower.

Subreach 1A

In subreach 1A, Cain (1997) compared the ratios of the low-flow channel widths in 1939 and 1989 to the 1939 active channel widths and the ratio of the 1980 high-flow channel width to the 1939 active channel width and concluded that the channel had narrowed over time. Comparative cross section surveys (1939 and 1996) indicated that the channel had degraded, which Cain (1997) attributed primarily to overextraction of sand and gravel.

Vertical Changes in River Channel Between 1914 and 1998

The comparative 1914 and 1998 cross section surveys enabled an evaluation of the absolute changes in channel elevation (Table 4.4). The data in Table 4.4 indicate that the base level for the study area has not changed at cross section 85. About 8.5 feet of degradation appears to have occurred at cross section 78, which would have the net effect of lowering the local water table. Aggradation at cross sections 81 and 70 may be due to local accumulation of sediment. The data show that there has been a general lowering of the thalweg elevation throughout subreaches 4A, 3, and 2, which ranges from 1.0 to 10.8 feet. It is highly likely that the reduced elevations are a result of recent subsidence caused by groundwater withdrawal and possibly hydrocompaction caused by irrigation (Poland et al. 1975, Bull 1964, Ouchi 1983). The maximum thalweg lowering is at cross section 29 (10.8 feet), which is located just downstream of Mendota, where 5–6 feet of subsidence has been reported (Ouchi 1983). The reported subsidence diminishes in the downstream direction to about 1 foot at about the Sand Slough Control Structure, which correlates fairly well with the data in Table 4.4.

In subreaches 1B and 1A (Table 4.4), the data indicate a net degradational trend. The very large negative values at cross sections 8C and 9 are directly due to sand and gravel mining. Lesser negative values through the subreach are the result of general degradation induced by the sand and gravel mining (Cain 1997). Cain (1997) concluded that mining resulted in an estimated sediment deficit on the order of 1,640 million cubic yards between 1941 and 1996. Degradation in the subreach may well have been greater if outcrops of bedrock at RM 255.5 and RM 265 had not provided local base level control (Cain 1997).

As part of the National Bridge inspection program, Caltrans has periodically resurveyed the channel bed profile at a number of bridges that cross the San Joaquin River and the Eastside Bypass (Table 4.5). Between 1972 and 1997, the minimum

thalweg location at the Highway 140 Bridge (RM 125.1) has declined by 1.6 feet. However, cross section 81, located upstream at RM 125.8, indicated channel aggradation of about 2 feet, which in combination with the stable base level at cross section 85, suggests that the changes in bed elevation in this portion of the study reach are a result of local factors. This conclusion tends to be supported by the bridge data from Highway 165 (RM 132.9), where no change is shown between 1972 and 1997. Cross section 78, located downstream of the bridge, appears to have had about 8.5 feet of scour between 1914 and 1998. In contrast, cross section 70, located upstream of the bridge, shows about 7 feet of aggradation (Table 4.4). At the Highway 152 Bridge, the data indicate aggradation of about 3 feet, which tends to be supported by field observations (Plate 35). Similarly, field observation tends to support the bed scour (about 3 feet) reported at the Highway 152 crossings of the Eastside Bypass (Plate 33). The Ness Avenue crossing of the Eastside Bypass also indicates that there may have been some scour (0.8 feet). The three bridges within subreaches 1A and 1B all show scour (Table 4.5). At Highway 145 (Skaggs Bridge), there has been about 3 feet of scour between 1970 and 1997. At Highway 99, there has about 5.6 feet of net scour between 1970 and 1997, with local gravel mining resulting in about 18 feet of scour between 1970 and 1985. At Highway 41 (Lanes Bridge), the net scour was about 5 feet between 1940 and 1997.

Lateral Changes in River Channel Between 1914 and 1998

Comparison of channel stationing between the 1914 survey and the U.S. Geological Survey (USGS) topographic quadrangles (1956–1965) that cover the study area of the San Joaquin River provides a measure of lateral changes in the channel that have affected the length of the reach. At the downstream end of the reach at Hills Ferry Bridge, a correction factor of 10.04 miles had to be subtracted from the 1914 stationing to equal the stationing on the USGS maps because of the difference in starting points at the Delta. The conversion factor was essentially constant within subreaches 5, 4B, and 4A, which indicates that channel length did not change appreciably in these subreaches between 1914 and 1956–1965. In subreach 3, the correction factor had to be increased to 11.0 miles, which indicates that the channel lengthened by about 4.5%. In subreach 2, the correction factor increased to 11.9 miles, an increase in channel length of about 8%. Subreach 2 has the highest sinuosity (Table 4.1) so the change was therefore expected. The correction factor remained constant for subreach 1B, indicating that channel length did not change appreciably. Ouchi (1983) compared sinuosities derived from topographic maps prepared in 1920–21 with the subsequent USGS topographic maps (1956–1965). He also concluded that there had been very little change, except in subreach 2. He concluded that the lack of change through time, especially since subsidence had occurred (Schumm and Khan 1972), was a result of the radically changed hydrology of the river, which was primarily caused by the construction of Friant Dam.

Mapping of the river planform identified on aerial photography in the 5 subreaches of the study area in 1937, 1957, 1978, and 1993 by Jones & Stokes Associates (1998) also indicated that there had been very little change in channel planform in that time frame. The combination of the closure of Friant Dam in 1942 and

distribution of the stored flows via the Madera and Kern canals, as well as implementation of the flood control project in the 1950s and 1960s, has greatly reduced the hydraulic energy of the river in the study area. Therefore, it is not surprising that there has been little change in channel planform.

Erosion and Sedimentation

As part of the field investigation of the study area, a qualitative evaluation of channel erosion and sedimentation was undertaken. Examples of erosional and depositional sites are shown on the plates in Appendix B. During the field reconnaissance, sediment samples were collected along the San Joaquin River and in the bypasses to characterize the sedimentology of the system. (Sample locations indicated by river mile [RM] location in Table 4.6.) In the upstream reaches, where the bed material was coarser, Wolman pebble counts (Wolman 1954) were used to develop the surface gradations.

Along the lower reaches of the San Joaquin River, bank erosion is ubiquitous on the outside of bends (Plate 23). Bank erosion rates are locally high during flood events in areas where the toes of the eroding banks tend to be composed of cohesionless sands (Plate 24). Low-elevation bank-attached sand bars are located on the inside of the bends, and these tend to support regeneration of riparian vegetation. In contrast, the floodplain surfaces tend to support only weed species and older riparian vegetation (Plate 23). The bed material in the sloughs is also sand sized, and bank-attached bars are also located on the inside of the bends. The portions of the bars at the lower elevations tend to show the effects of salt accumulation (Plate 25), which may limit vegetation regeneration.

The highly contorted shape of many of the bends in both the San Joaquin River and the sloughs is due to differential erodability of the floodplain sediments. Highly erosion-resistant, cohesive flood basin sediments (Plate 27) are eroded by mass wasting processes (Plate 26) rather than by fluvial entrainment, as is the case where the banks are composed of sands (Plate 24). The bank erosion appears to be the major source of sediment that is deposited on the floodplain during larger flood events, such as in 1997 (Plate 28).

Erosion of agricultural fields that border the channel is a significant source of sediment for the river and the sloughs (Plates 29 and 30). Downstream transport of sediment is greatly complicated by the control structures that are used to split flood flows among the mainstem and the bypasses (Plate 31). Since the majority of sediment in transport is sand-sized and finer, the sediment is probably distributed in proportion to the flows at the bifurcation points.

A considerable amount of sediment has accumulated in the Eastside Bypass downstream of the Sand Slough Control Structure (Plate 32). Some of the sediment is undoubtedly derived from the mainstem San Joaquin River upstream of the bifurcation point. However, significant gully erosion in the bed of the Eastside Bypass, both

upstream (Plate 33) and downstream of the Highway 152 crossing, appears to be responsible for most of the sediment that is accumulating in the Eastside Bypass downstream of the Sand Slough Control Structure. Flood flows in the bypass generate sufficient shear stress on the bed of the bypass to erode the caliche hardpan that has formed in the fan-margin soils (Plate 34). Ash Slough is also reported to be a major sediment producer for the Eastside Bypass (Hill pers. comm.).

Within the San Joaquin River, the locations of bank erosion and sediment supply and sediment deposition are controlled to a large extent by the flows in the system. Downstream of Sack Dam, where the channel is dry most of the time, the distribution of the sediment, derived primarily from upstream bank erosion, is dependent on the duration of flood flows (Plate 35).

Upstream of Sack Dam, the sand-sized sediment derived from bank erosion (Plate 36) can be conveyed by the Delta-Mendota Canal flows that are distributed downstream via the river (Plate 37). Riparian vegetation is well established in the subreach because of the perennial flows, and, where present, it increases the resistance to erosion of the banks (Plate 38). However, because a considerable amount of sediment is stored upstream of Mendota Dam and the Delta-Mendota Canal water is essentially sediment free, erosion of nonvegetated banks is probably accelerated. General bed degradation, as seen from the comparative surveys of the subreach (Table 4.4), may be due to the clear water releases from the Mendota Dam. Wherever hydraulic energy in the subreach is reduced either as a result of backwater generated by a sharp radius of curvature bend or by a flow expansion zone, there is sediment deposition in the channel (Plate 38) or in the overbank areas (Plate 40).

Upstream of Mendota Dam, the high-amplitude meander bends are storing a considerable volume of sediment (Plate 40). The combined effects of the bifurcation structure at the head of the Chowchilla Bypass, the low slope because of the high channel sinuosity, and possibly the backwater effect of Mendota Dam are responsible for the severe aggradation in this subreach of the channel.

Bank erosion is the primary source of sediment upstream of the Chowchilla Bypass (Plate 16). Considerable volumes of sediment are stored in the bed of the channel upstream of the bifurcation structure (up to 0.5 million cubic yards/mile of channel) (Plate 15). It has been estimated that the sediment retention basin at the head of the Chowchilla Bypass (with a capacity of about 200,000 cubic yards) fills up with sediment every 2 to 3 months (Hill pers. comm.).

Upstream of Gravelly Ford, the bed material in the channel of the San Joaquin River becomes a lot coarser (Plate 41). The coarser bed material is probably derived from bank erosion and, to some extent, from Little Dry Creek (Cain 1997). Releases by USBR have created a perennial flow channel that is armored at low flows and flanked by well-developed riparian vegetation (Plate 42). Because the San Joaquin River is inset below flanking terraces, flood flows are confined (Plate 43) and the gravel-sized bed material is mobilized (Plate 44). Bed material transport in the upper reaches of the river is significantly affected by the presence of the breached sand and gravel pits (Plates 19

and 20). Where flood flows are confined by terraces, coarse bed material can be mobilized (Plate 45).

Nine bulk sediment samples were collected in the lower sand-dominated part of the study area. The gradation curves for the samples are shown on Figure 4.7. Four Wolman pebble counts were conducted in the upper part of the study area where the bed material is composed of gravel-sized sediment. The gradations from the Wolman counts are shown on Figure 4.8. Table 4.6 presents the size distribution parameters (D_{16} - 16th percentile; D_{50} - median size; D_{84} - 84th percentile; D_s - gradation coefficient) that were derived from the gradation curves. The data in Table 4.6 show a general trend of coarsening of the sediments in the upstream direction. The D_{50} increases from about 0.5 mm in subreach 5 to 90 mm in subreach 1A. From about Highway 165 upstream to Firebaugh, the bed material is primarily composed of sand (<2 mm). Between Firebaugh and Mendota, the bed is predominantly sand but some coarser gravel is present (>2 mm). Gradation coefficient (D_s) values in excess of 3 show the presence of gravel in the bed material samples. Upstream of Gravelly Ford, the D_{50} values increase by an order of magnitude, and the D_s values drop to less than 2, which is indicative of an armored condition.

Two sediment samples (S-2, S-3) were collected in the Eastside Bypass to evaluate the caliber of the sediment being transported. Table 4.6 shows that the sediments are primarily sand-sized, but some fine gravel is also present.